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Be and C mixed material studies

Parametric studies on carbon chemical erosion mitigation dynamics in Be seeded deuterium plasmas

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In ITER strike point region, strong interaction between Be and C is anticipated

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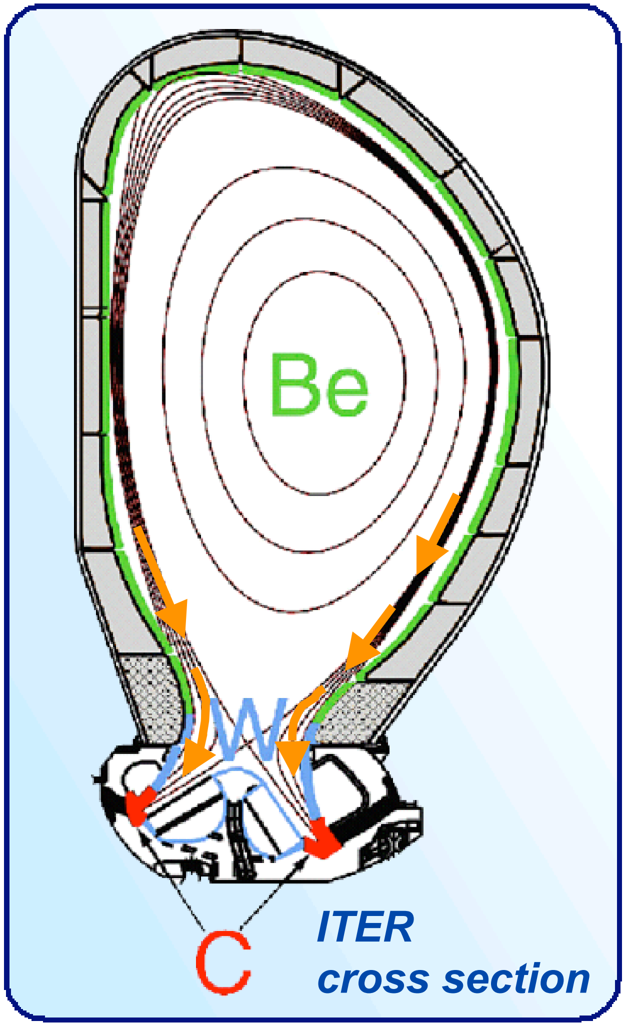
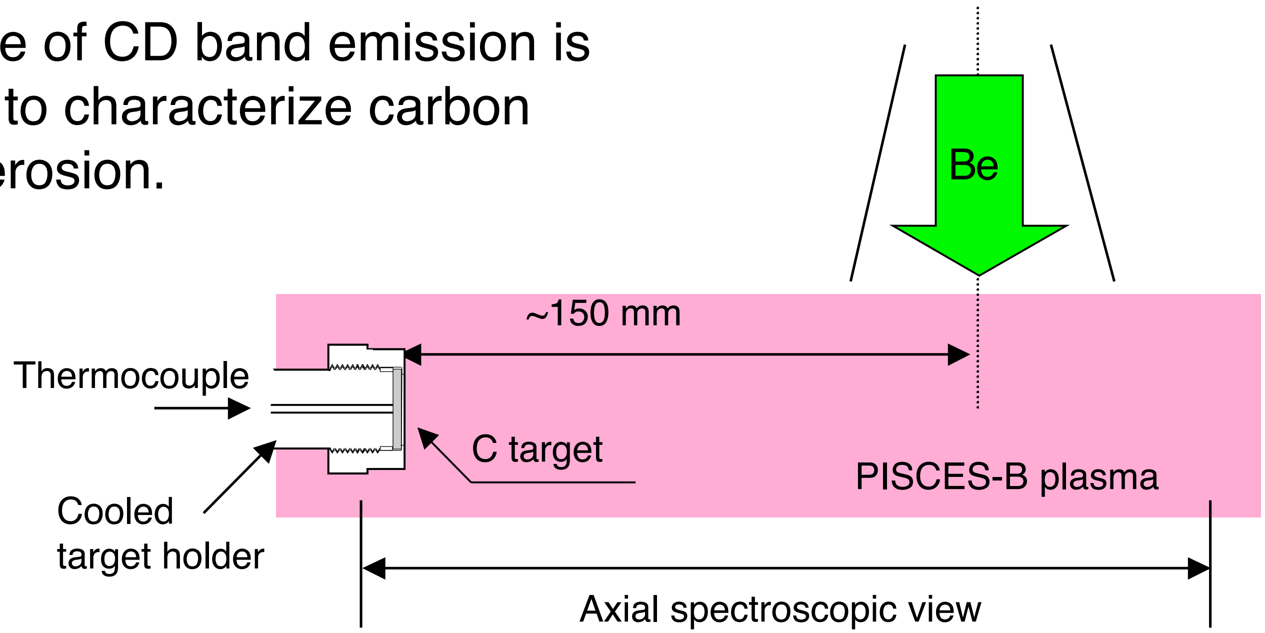
- Previous results from PISCES-B;
  Carbon erosion is reduced by Be impurity in the plasma.
- Next questions:
  - How quickly is carbon erosion suppressed by Be layers formation?
  - What are the important parameters responsible for carbon erosion mitigation time (protecting Be layer formation time)?

Help to better predict ITER and determine if Be layers would form between ELMs



PISCES-B allows to expose a sample to Be seeded plasma

- The concentration of Be ion within the plasma column, measured with absolutely calibrated spectroscopic system, can be controlled by varying the temperature of the oven.
- Axial profile of CD band emission is monitored to characterize carbon chemical erosion.



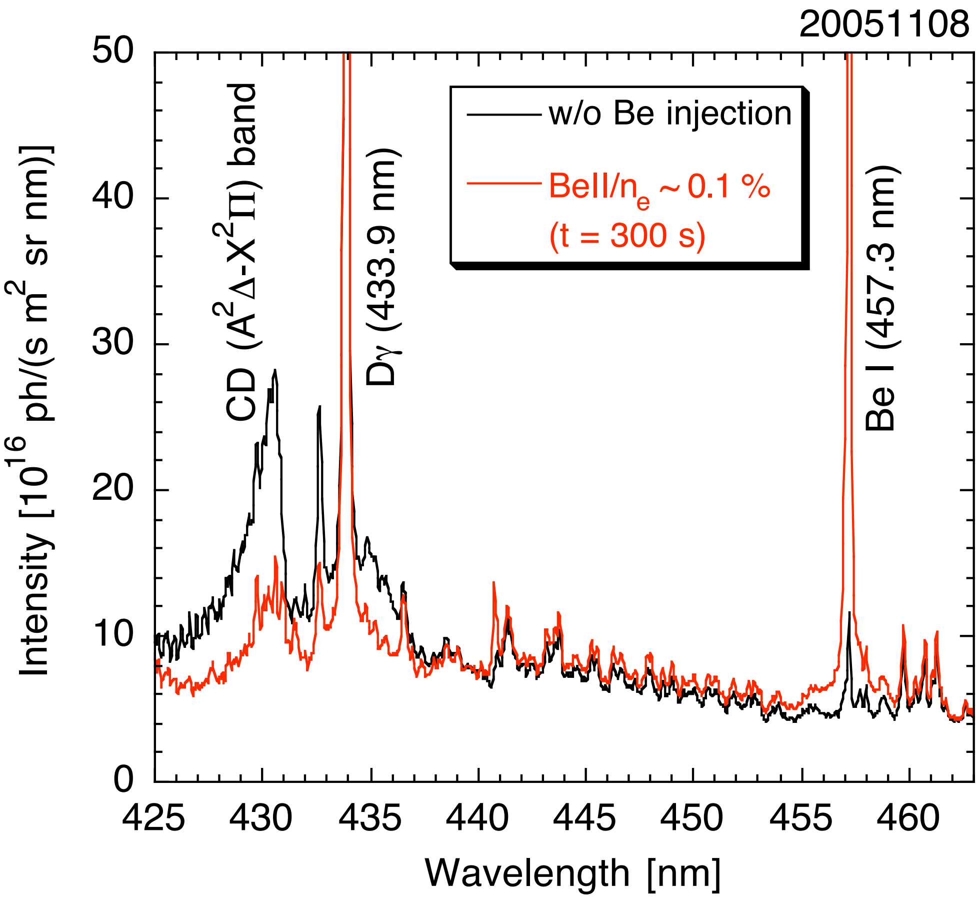
Small amount of Be impurity in the plasma suppresses carbon chemical erosion

CD band intensity is decreased with Be injection.

Carbon chemical erosion is reduced.

Decay rate of CD band is used to measure Be surface coating time.

$\Gamma_i \sim 3\text{x}10^{22}$ $m^{-2}s^{-1}$, $T_s \sim 960$ K, $E_i \sim 40$ eV



XPS analysis shows formation of beryllium carbide (Be_2C), responsible for carbon chemical erosion mitigation

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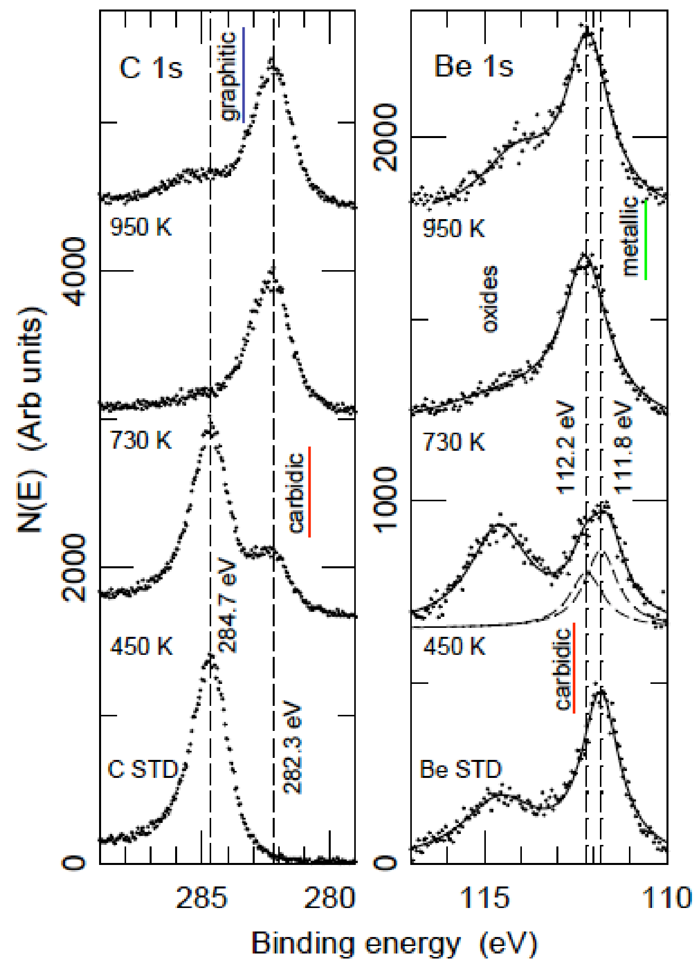
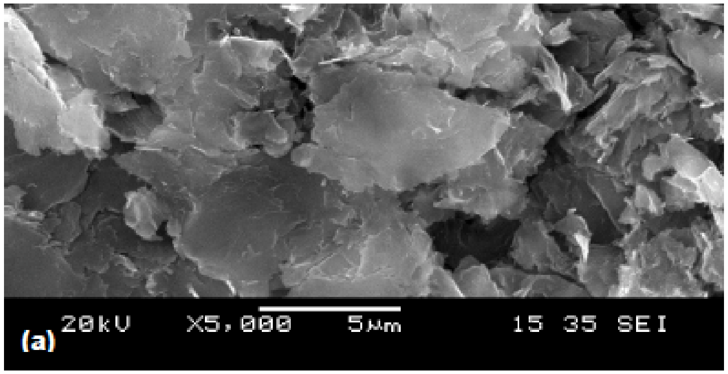
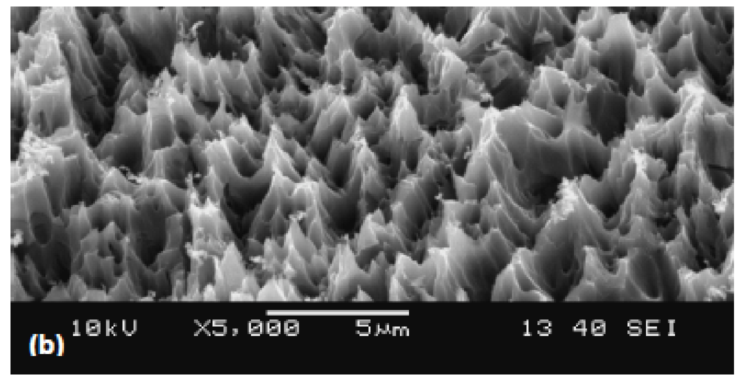
- XPS analysis of Be on C sample surface to examine chemical binding of elements
- After Be seeding D-plasma exposure,
  - — A carbidic peak appears and a graphitic peak disappears in C 1s spectra.
  - — Also in Be 1s spectra, a carbidic peak emerges.
  - — Carbide forms more readily at higher surface temperature



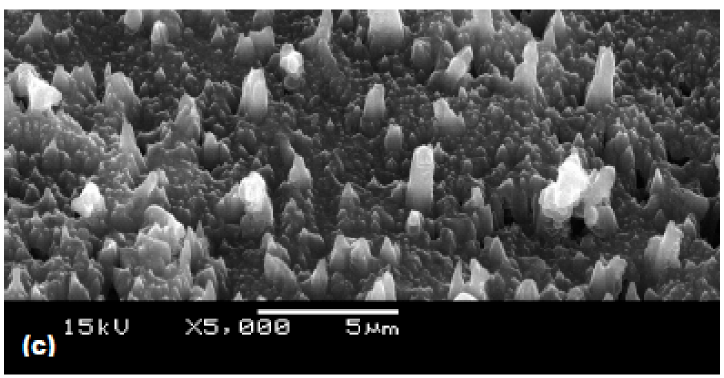
Surface morphology changes with Be impurity



Unexposed ATJ graphite target
Rough and porous surface
(typical of machined graphite)



D plasma exposure with no Be
D ion fluence ~ $2x10^{26}$ m^{-2}, T_s ~ 600K
Cone like appearance (chemical erosion)



D/Be mixture plasma exposure

D ion fluence ~ $1.2x10^{26}$ m^{-2}, BeII/n_e ~ 0.1 %, T_s ~ 600 K

Smoother surface (sub-micron level roughness), due to deposition of Be

Decay time of CD band emission (Be layer formation time) is measured with spectroscopy

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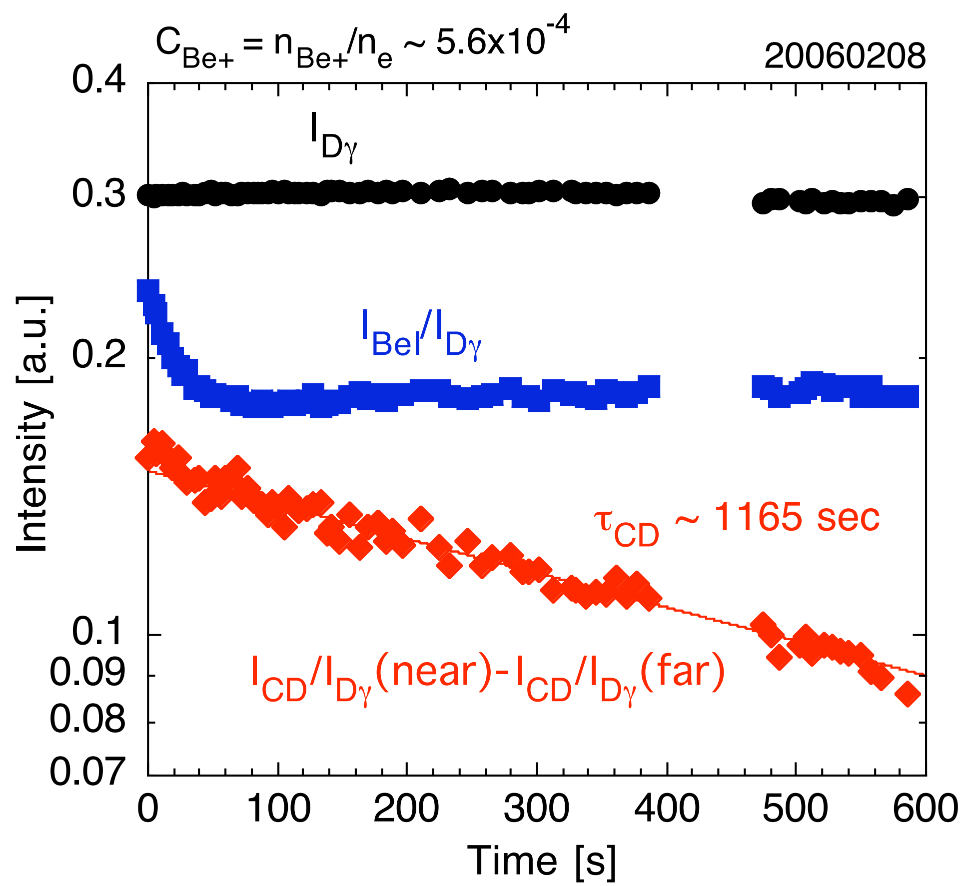
- $I_{D\gamma}$: To monitor background plasma change
- $I_{BeI}/I_{D\gamma}$:

  To monitor Be injection
- $I_{CD}/I_{D\gamma}(near)-I_{CD}/I_{D\gamma}(far)$:

  CD band intensity far from the target is subtracted from that near the target to eliminate changes in CD band originated from wall C.
- n_{Be+} from $I_{BeII(467.3nm)}$



Parametric studies on CD band decay time, in other words, protecting Be layer formation time

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Dependences on:

- Be ion concentration (c_{Be+})
- Incident ion energy (E_i)
- Surface temperature (T_s)
- Incident ion flux (Γ_i)
- Scaling expression (c_{Be+}, E_i, T_s, Γ_i)

τ_{CD} decreases with an increase in Be ion concentration as expected

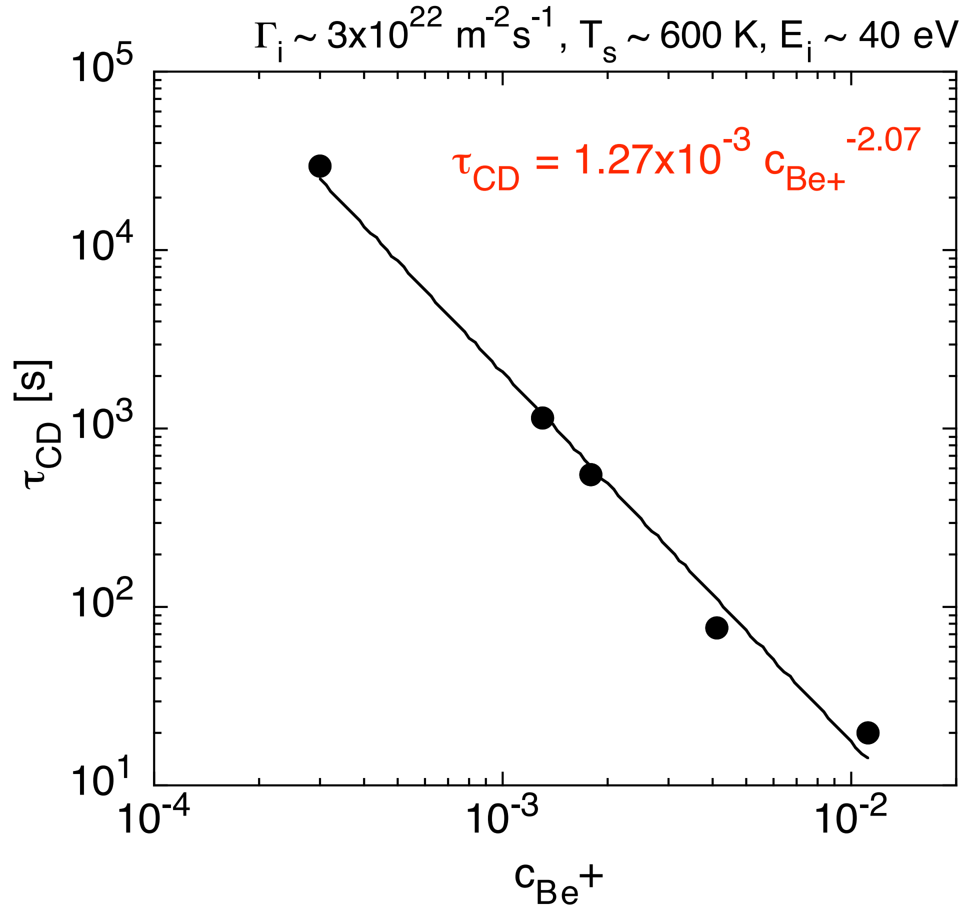
- Scan c_{Be+} while keeping other parameters, E_i, T_s and Γ_i constant as much as possible.

- Fit of power function,

  $\tau_{CD} = \alpha\ c_{Be+}^{\beta}$, gives

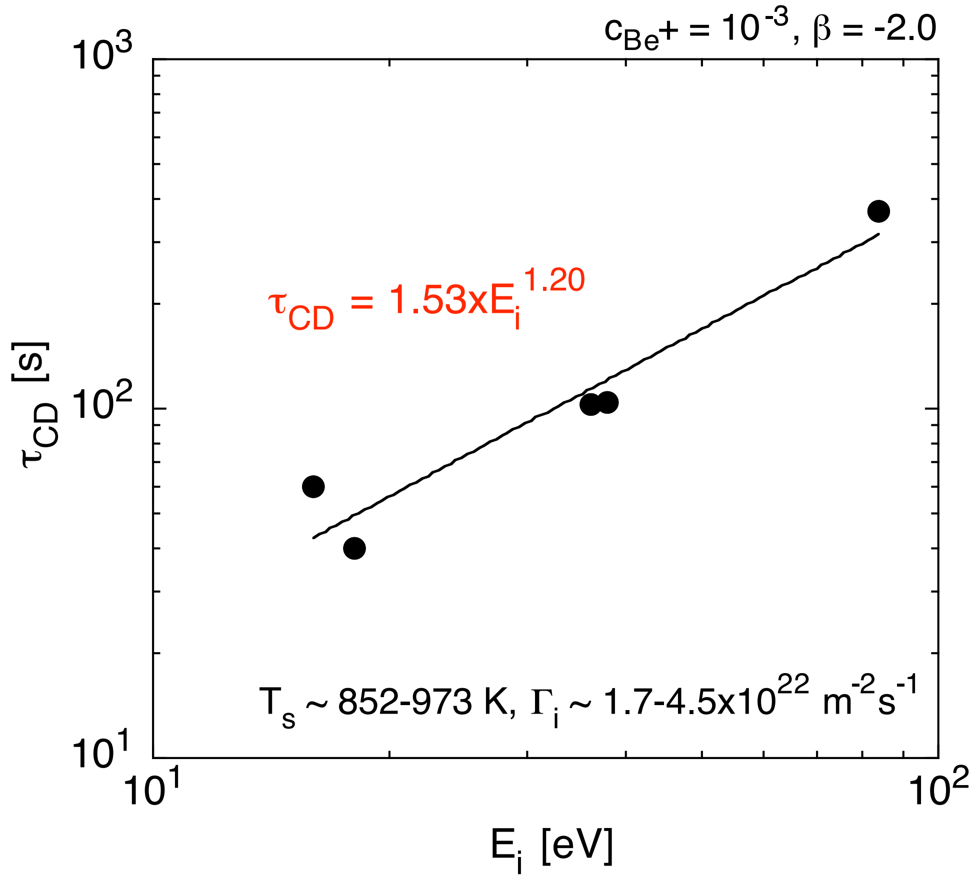
  $\alpha = 1.27\mathrm{x}10^{-3}$, $\beta = -2.07$, showing relatively strong dependence.

- Scan each parameter, E_i, T_s and Γ_i, while keeping others ~constant



τ_{CD} is nearly proportional to incident ion energy at low energy range

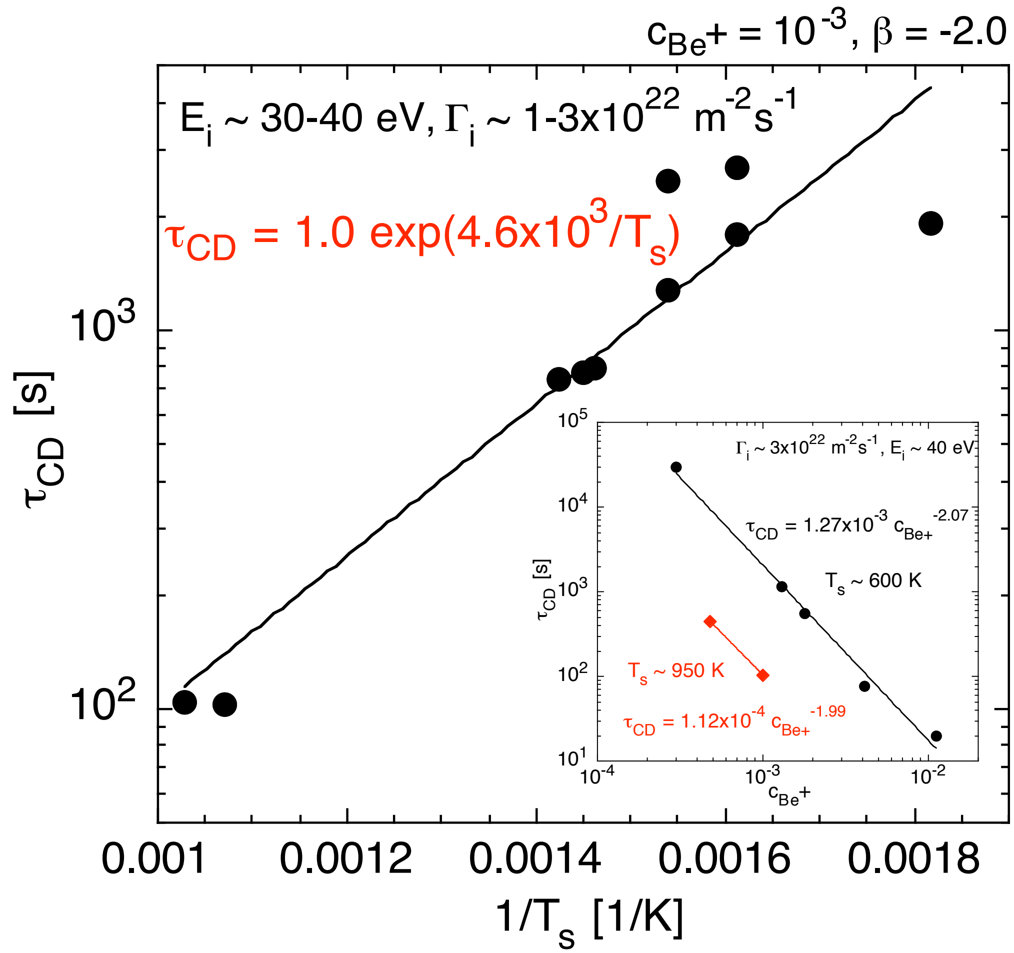
- Derive τ_{CD} at $c_{Be+} = 10^{-3}$ by assuming $\beta = -2.0$ in power law $\tau_{CD} = \alpha\, c_{Be+}{}^{\beta}$ to compensate c_{Be+} dependence.
- A power function fit reveals τ_{CD} is nearly proportional to E_i.
- At higher incident energy, Be deposited on C target can be more readily sputtered before Be_2C is formed, resulting in longer τ_{CD}.



τ_{CD} strongly depends on surface temperature

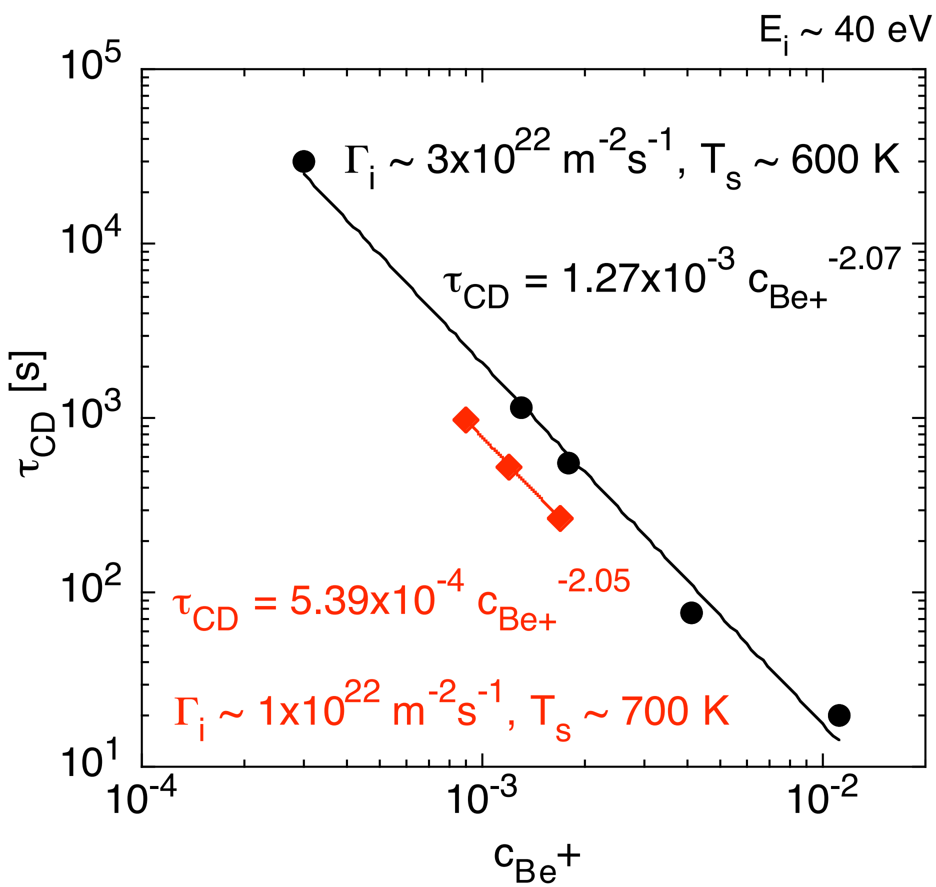
- At a higher surface temperature T_s of ~ 950 K, τ_{CD} is shorter than that at T_s ~ 600 K by a factor of ~ 20.
- Quicker formation of beryllium carbide (Be_2C) at higher T_s.
- The parameter β in $\tau_{CD} = \alpha\, c_{Be+}^{\beta}$ at T_s ~ 950 K is nearly the same as that at T_s ~ 600 K.

  ⇨ The same trend with respect to c_{Be+}.



τ_{CD} has possibly a very weak dependence on incident ion flux

- At a lower incident ion flux of ~ 1×10^{22} $m^{-2}s^{-1}$, τ_{CD} is found to be approximately 2.5 times smaller than that at Γ_i ~ 3×10^{22} $m^{-2}s^{-1}$.
- However, higher T_s can lead to shorter τ_{CD}.
- Again, the parameter β is about -2.



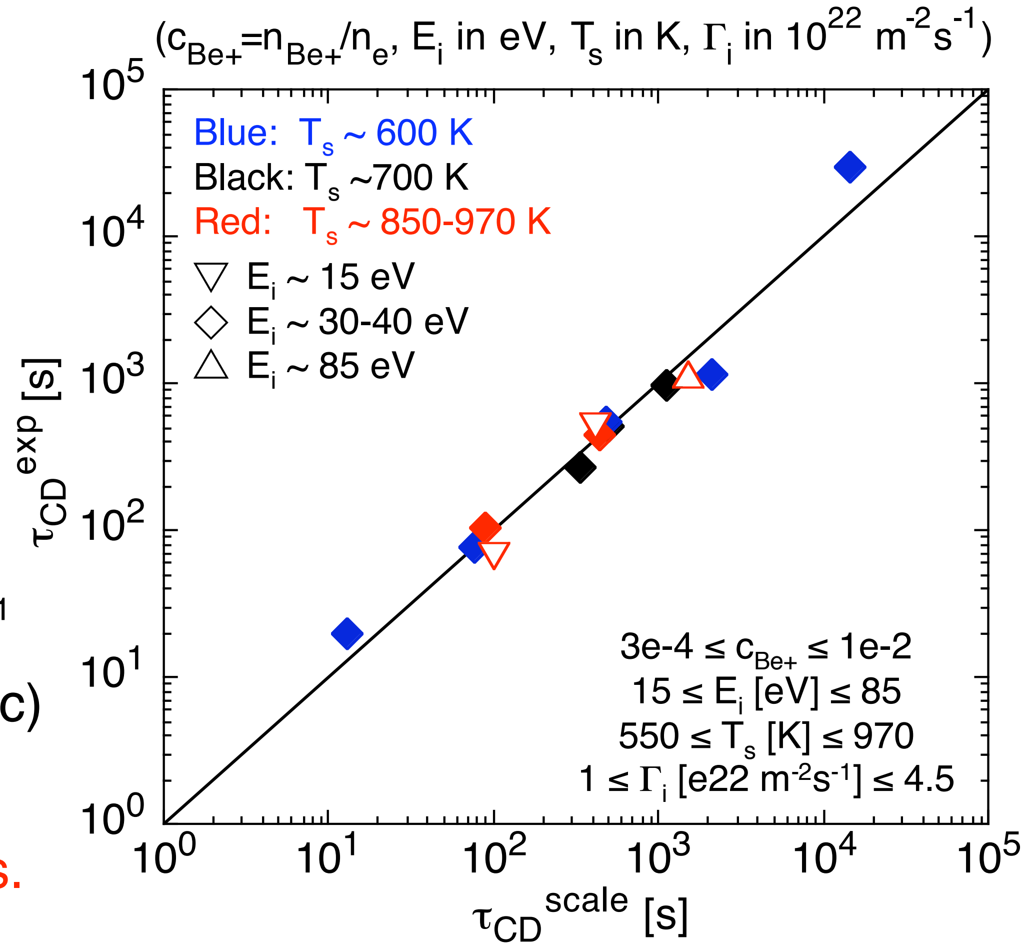
τ_{CD}^{exp} obey the scaling law well; τ_{CD}^{scale} [s] = 1.1e-7 $c_{Be+}^{-1.85} E_i^{1.0} \Gamma_i^{-0.5} \exp(4.7e3/T_s)$

- Weak negative power law dependence on Γ_i.
- At higher flux, redeposition fraction of Be is increased, leading to shorter τ_{CD}.
- Extrapolation to ITER*

  $\left\{ \begin{array}{l} c_{Be+} = 0.05,\ E_i = 20\ \text{eV} \\ T_s = 1200\ \text{K},\ \Gamma_i = 10^{23}\ \text{m}^{-2}\text{s}^{-1} \end{array} \right.$

  ⇨ τ_{CD} ~ 9 msec (<< 1 sec)

- Protecting Be layers can be formed between ELMs.



*G. Federici et al., JNM 266-269 (1999) 14.

Conclusion

- Small beryllium concentration in the plasma suppresses carbon chemical erosion.
- XPS analysis shows beryllium carbide (Be_2C) layer is formed on a carbon sample after Be seeding deuterium plasma exposure with the surface temperature above 450 K.
- Parametric studies on carbon chemical erosion mitigation dynamics reveal the following dependences;

Strong	Surface temperature $\exp(4.7e3/T_s)$ (600 K - 970 K)
	Be concentration $c_{Be+}^{-1.9}$ (3×10^{-4} - 1×10^{-2})
	Incident ion energy $E_i^{1.0}$ (15 - 85 eV)
Weak	Incident ion flux $\Gamma_i^{-0.5}$ (1-4.5×10^{22} $m^{-2}s^{-1}$)

- More work is still needed at higher T_s, higher E_i and higher Γ_i.